DEEP SEA *CORALLIUM SP.* IN THE NORTHWEST HAWAIIAN ISLANDS BASAL DIAMETER-COLONY HEIGHT CURVE AND COLONY HEIGHT-AGE CURVE

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Deep Sea Corallium Sp. in the Northwest Hawaiian Islands Basal Diameter - Colony Height Curve and Colony Height - Age Curve

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In the Northwest Hawaiian Islands and Emperor Seamounts different seamounts have been subjected to varying levels of fishing impacts where some seamounts have never been fished, some where fishing stopped ~30 years ago, and some where fishing continues today. In this study we utilize the three different treatment types, never fished, recovery after fishing stopped ~30 year ago, and currently fished to assess recovery rates of the deep-sea coral *Corallium* sp. after damage by anthropogenic fishing impacts. The goal is to ascertain the recovery rate of the deep sea coral, *Corallium sp.*, samples by comparing the population structure of the seamounts within the three different treatment types. *In-situ* photos will be taken at various locations and the software photoQuad (Tyronis, and Sini, 2012.) will be used to make fast, reliable and relatively inexpensive size measurements of *Corallium sp*. samples at each site. The images that are taken and the measurements made will be used to generate a basal diameter to height curve and a colony height to age curve. These findings are critical to determing the recovery rate of these keystone habitat builders on seamounts which are biodiversity hotspots in the deep ocean. Knowing the rate of recovery after damage by anthropogenic fishing activities that contact the seafloor is important to high seas conservation and management efforts.

NOMENCLATURE

HURL	Hawaiian Undersea Research Laboratory
KOK	R.V. Ka`imikai-O-Kanaloa
NWHI	Northwestern Hawaiian Islands
DSC	Deep-sea Coral
Sub	Submersible Vehicle
b-d	Basal-Diameter

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CHAPTER I

INTRODUCTION

The Northwestern Hawaiian Islands and Emperor Seamount chain are in one of the most remote locations on the planet that is not easily accessible to most people (figure 2). Their extreme location means very little is know about the environment. The Hawaiian peoples have gone to great lengths to protect their sacred lands throughout much of the island chains. Access to the Marine National Monument Papahannamokuakea is has highly restricted with strong management plans. The restrictions led to portions of the region being relatively protected from fishing activities and other anthropogenic activities that can have major impacts on marine habitats. This particular region is quite incredible and is uniquely suited to study the effects of fishing activities on these important ecosystems. Unlike other marine regions like coast lines or islands in more populated areas the isolation has limited the amount of direct human impacts to fishing activities.

FIGURE 1. MAP OF PACIFIC OCEAN (HTTP://MAPSOF.NET/PACIFIC-OCEAN/PACIFIC-OCEAN)

FIGURE 2. MAP WITH LABEL OF NORTHWESTERN HAWAIIAN ISLAND AND SOUTHERN EMPEROR SEAMOUNT CHAIN WITH SITES USED IN THIS STUDY LABLED (BACO-TAYLOR, A., ROARK,

Fishing Impacts

Three different treatment types are being analyzed in this study. One that is still being fished, one that was fished up until 30 years ago, and one that has never been fished (Fig3). Fishing in the region has focused on pelagic armourhead (*Pseudopentaceros wheeleri*) and for alfonsino (*Beryx splendens)* at depths of 300-600m (Table 1). In addition there have been active precious coral fisheries including the pink coral *Corallium secundum* and the red coral *C. laauense* (octocoral Family Coralliidae) over the last couple of decades (Grigg 2002). At least 3 sites in each treatment type have been surveyed in order to asses the recovery rates of the *Corallium* sp. corals which requires good size-age class information of *Corallium* sp. at each site. In this study size-age class information will determined using a basal diameter to height curve and a colony height to age curve to calculate the size-age class. The determination of the recovery rates of the deep sea coral *Corallium sp.* by comparing the population structure of the differing seamounts will increase our understanding of the rate of recovery after damage by anthropogenic activities that contact the seafloor.

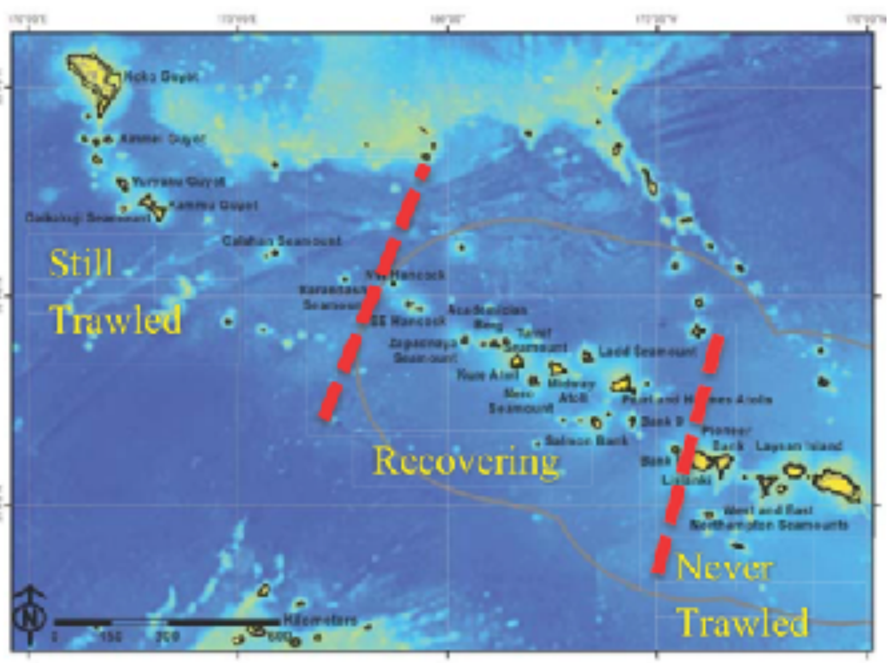


FIGURE 3 (LEFT). MAP OF NORTHWESTERN HAWAIIAN ISLAND CHAIN AND EMPEROR SEAMOUNTS. SEPARATION OF TREATMENT CLASSIFICATIONS. (BACO-TAYLOR, A., ROARK, B. 2017.)

How and Why?

There are various methods of estimating the growth rates and ages of individual DSC including tagging, counting what are assumes to be annual growth bands, and radiocarbon dating (c.f. Roark, et. al. 2009). *In-situ* imaging combined with digital estimates radial diameters and colony height is a new and cutting edge method that allows for inclusion of specimens in the data pool. By using images to make estimations of growth rates and ages, we will be eliminating the need to remove specimens from their habitat. Being minimally invasive while equally as reliable is a necessity.

TABLE 1 (BELOW). TRAWLING HISTORY FOR SEAMOUNTS LOCATED IN THE NORTH-WESTERN HAWAIIAN ISLAND CHAIN AND THE EMPEROR SEAMOUNT CHAIN. (BACO-TAYLOR, A., ROARK, B. 2017.) ONG- ONGOING. NS - NOT SURVEYED

Feature Name	Posit Lat N	Posit Long E/W	*Last Year Trawled	Coral Obs	Total Catch **mt	SA (km^2)	Catch per km^2	C (km)
Koko Smt	35 15.0	171 35.0	Ong	ns	92500	3874	24	397.7
Yuryaku Smt	32 40.2	172 16.2	Ong	ns	98000	72.7	1348	41.2
Kammu	32 10.0	173 00.0	Ong	ns	28000	610.3	46	166.7
NW Hancock	30 16.2	178 43.2	1986 - ong	ns	98300	5.6	17558	9.2
SE Hancock	29 47.4	179 04.2	1986	ns	92500	10.9	8525	16.3
Zapadnaya	28 54.0	-179 36.0	1977	Yes	11500	42.3	272	33.2
Pioneer Bank	26 00.0	-173 26.0	Never	Yes		143.0		103.1
W Northampton	25 30.6	-172 24.6	Never	ns		81.48		85.8
E Northampton	25 22.2	-172 04.2	Never	ns		37.96		53.7

How:

In order to determine the size and age classes of the deep-sea coral *Corallium sp.* across multiple seamounts in the Northwest Hawaiian Islands, I will develop a linear regression of basal diameter and colony height from observed (*in-situ* photos) specimens and collected *Corallium sp.* specimens. Then, this linear regression will be used to estimate the basal diameter of *in-situ* measured colonies where only height data is available. With the basal-diameter one can estimate the age of the colony using radiocarbon derived radial growth rates for *Corallium sp* from previous studies in the region (Roark et al., 2006). In-situ photos will be taken along transects at different depths at each site and the software photoQuad (Tyronis and Sini, 2012) will be used to make fast, reliable and relatively inexpensive measurements colony height and radial diameter (when possible) of the *Corallium sp*. in these seamounts. Similar studies have been done in the Gulf of Mexico on black coral species (Etnoyer, et al., 2017.) and in the Northwest Atlantic (Bennecke, et al., 2016.). The coral specimens and in-situ images are collected as part of a study regarding the impacts of fishing in these specific seamounts

Through a series of submersible dives, videos were taken where I was able to pinpoint time when *Corallium sp.* were visible on screen. Image grabs from the video were taken and manipulated in the photoQuad software. By doing this I could make in-situ measurements of colony height and radial diameter that will be compared to the same measurements of the specimens onboard the ship and in the lab. Basal diameters are difficult to determine so we will also determine a height to basal diameter curve. The curve will help determine the relationship between basal diameter of *Corallium sp*. and their respective heights. The relationship observed will then be used to determine the basal diameter based and colony height of other colonies that were not collected in order to develop a community size and age class structure. The colony height and/or basal diameter will be compared to radiocarbon derived growth rates in order to determine the age of an individual specimen. From the size and age data, we will determine the various size and age classes of *Corallium sp.* across multiple seamounts in the Northwest Hawaiian Islands.

FIGURE 5 (RIGHT). IMAGE OF PISCES V ON DECK OF KOK. SEPT. 3, 2017

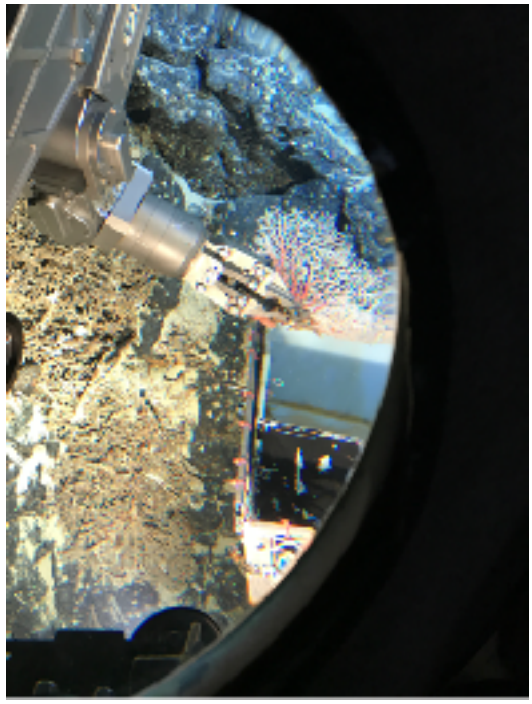
FIGURE 4 (LEFT). IMAGE OF PISCES IV WITH HURL CREW MEMBERS. SEPT. 17, 2017

Why:

Very little is known about DSC, especially when compared to surface corals. In the news today we hear a lot about coral bleaching and images of the Great Barrier Reef or tropical Hawaiian reefs. That is in part due to difficulties related to sampling and observing these DSC ecosystems. Submersibles and ROVs have made these corals more accessible, and as a result we can discover more about their biology, their growth rates, and their longevity (Roark et al.,. 2006). These corals also play a large part in the commercial jewelry and fisheries industries. Having the ability to perform these types of analyses with minimal amounts of disruption to the surrounding ecosystem is important to studying these ecosystems without damaging them. Leaving specimens in their natural environment is a good step in the direction of more sustainable research and science. Typically samples would have to be removed in order to perform radiocarbon analyses on them, to determine their age (Fig. 6). With this method, we can simply visit, take pictures, and get the same results.

Marine conservation and protection are paramount to the discussion of the impacts of anthropogenic forces on all of the earth,. All of our data comes from the Marine National Monument or right outside of it. Take it a step further and the geochemical and isotopic data we can

FIGURE 6. IMAGE OF LAUUENSE SPECIES BEING SAMPLED.
PISCES V DIVE NUMBER 900.



gather from these corals, can provide insight on human-induced environmental changes by re-constructing past changes in the ocean environment.

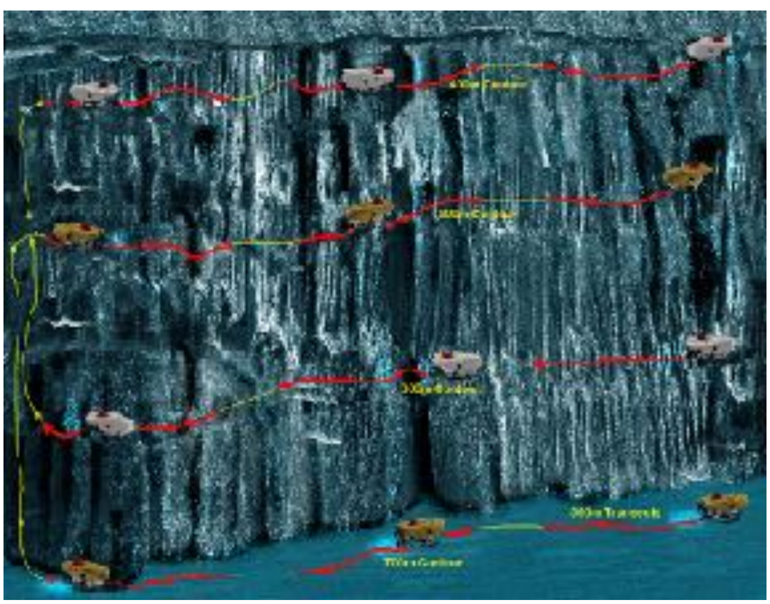
CHAPTER II

METHODS

Collection in the Field

All of the samples in this specific study were collected and videoed between September and November 2017. They were collected between 300m-800m on and around the various seamounts. Potential samples were identified during either transects or sampling dives. Figure **7** represents the transect path typically taken on a seamount by the two HURL submersibles, Pisces IV and V. Samples could be taken at the landing point of the submarine, or marked and gone back for collection once the transect was over (on that day or on a sample collection dive).

FIGURE 7. IMAGE OF TRANSACT TRACKS AT SEAMOUNT. (BACO-TAYLOR, A., ROARK, B. 2017.)



Sample collections had to be made by visiting the ocean floor in PISCES IV (piloted by Max Cremer) and PISCES V (piloted by Terry Kearby) submersible vehicles in and around the NWHI. Videos were taken starting once the submersibles hit the bottom and were stopped as the submersibles left the bottom. Everything that was seen in the videos is what was seen by the people in the submersibles. Identifications of the species was made on the spot by either the pilot, the first observer, or the second observer and was noted in the dive logs. Upon video inspection a secondary identification of the species is made to confirm the original identification.

In order to retrieve in-situ photos, someone in the submarine had to monitor the videos

FIGURE 8. IMAGE OF INTERIOR OF PISCES V. HD AND SD CAMERAS. OCT. 8, 2017. PISCES V DIVE NUMBER 900

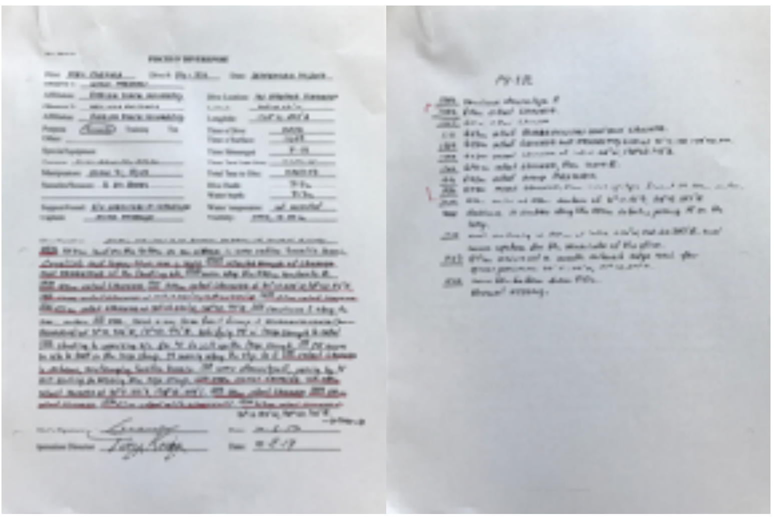
and manipulate the cameras. To accomplish this, the second observer inside the sub had to watch the video feed on the interior wall and move the camera around to better capture what was seen through the observation ports. Two separate cameras were used in the recording of the dives. One was an SD camera (right screen in figure 8) that had the time and date attached. The other was an HD camera (left screen in figure 8) with better imagining capabilities. Both were monitored and manipulated at the same times, using one controller. Once the videos were captured in the submarine, they were loaded onto a hard drive, labeled by dive number. These videos were duplicated on the ship the night they were retrieved.

The samples used came from various dives on Pisces IV and Pisces V. From Pisces IV dives are numbers: 326 (North Koko Seamount), 328 (South Koko Seamount), 332 (NW Hancock), 336 (Brooks Bank), 340 (West Northampton), 341 & 344 (Pioneer Bank). Pisces V's data comes from dives: 889 (SE Hancock), 895(Koko), 901 (NW Hancock), 906 & 907 (East Northampton), and 910 (West Northampton). These dives range from September 15, 2017 to November 11, 2017.

Preparations

To capture images on the videos, reviewing the videos multiple times was necessary. To accomplish this most efficiently, the dive logs (figures 9 & 10) from the pilots (Max Cremer and Terry Kearby) and dive logs from the first and second observer (figures 11 & 12) were read. Examining the logs made pinpointing the exact moments corals were recovered possible. Both sets of logs were studied, each containing sample identification, their location (both depth and the approximate coordinates) of sample retrieved or imaged, water temperature, and any notable features of the sample's surroundings. To organize the data, a count of total species viewed and recovered was taken initially. This prioritized specific dives, and more exactly, specific times within the dives when images of *Corallium sp* were likely to be found. A log was then made to keep track of all of this information.

The videos were separated by their size, with the HD ones taking up more space than the SD ones. When going back through the videos, this posed a challenge in matching specific times and locations, because the SD videos were in real time while the HD ones were not. Both videos were watched simultaneously, the SD for the time and date to match with dive logs, the HD for better image quality. In order to match the time from the SD video to the HD video, visual comparisons had to be made to match in both videos. Once a specimen was visible on screen, both videos were paused to take a screen grab. The images were saved with a time and video stamp to easily identify at which point in which video the image belongs to. Once that was done, an image ID was added to a document that correspond to the actual dive date, location, and approximate depth.



FIGURES 9 AND 10. FIGURE 9 IS AN IMAGE OF PAGE ONE OF A DIVE LOG SHEET FILLED OUT BY THE PILOT OF THE SUB AFTER THE DIVE. FIGURE 10 IS PAGE TWO OF THIS LOG. PISCES IV DIVE NUMBER 332. SEPT. 30, 2017. WRITTEN BY MAX CREMER.

FIGURES 11 AND 12. FIGURE 11 IS AN IMAGE OF THE FIRST OBSERVERS OBSERVATIONS. FIGURE 12 IS THE SECOND PAGE OF OBSERVATIONS. PISCES IV DIVE NUMBER 332. SPET, 30, 2017.

“Laboratory” Methods

Once the images were documented they were transferred into the photoQuad software. In the software, each image was analyzed individually. Once an image was selected, the distance of the lasers in the image were calibrated to 25cm. The software program does this by converting pixels to centimeters. When the image was properly calibrated, a measurement is taken with the permanent measurement tool. Each sample is measured from its base to the top of the sample in the image for the height measurement. I determined the base to be either where growth was determined to have started from nearest to the samples attachment point. This exact place varied image to image based on the sample itself, along with the orientation of the camera when the image was taken. The measurement tool started at the base point, and went up as straight as it could be while sticking to the same branch the base was most aligned with. This proved to be difficult to ascertain on the samples whose images were not taken at a portrait angle. A reasonable amount of flexibility had to be made for these images introducing additional error in the measurements.

Multiple copies of all of the images were taken, allowing progress to be tracked. For each sample

FIGURE 13. IMAGE OF SECUNDUM SAMPLE BEING MEASURED IN THE PHOTOQUAD SOFTWARE.

FIGURE 14. IMAGE OF LAUUENSE SAMPLE BEING MEASURED IN THE PHOTOQUAD SOFTWARE.

image three copies were made: one that was before any treatment on the image was done, the second was taken while treatment was being done on the image, and the third was the saved image from photoQuad. As the images were being measured (treated), their measurements were recorded in order to ascertain the height and basal diameter of the specimen. These measurements were taken with great care, the ends of the measurement tool placed at the precise, predetermined location.

Once the measurements were made and recorded accordingly (figures 13 and 14), the values graphed in a scatterplot. This is done to correlate the relationship between the basal diameter and the height of each specimen. The x-axis of graph corresponded to height and the y-axis to the basal-diameter.

The height to basal diameter equation is used to calculate basal diameter of specimens when measuring the basal diameter isn't possible. The basal diameter is used in combination with the radial growth rate of 110 µm/yr (Roark et al., 2006) to estimate the age of a sample. The calculated age then became the x-axis of curve 1B and the y-axis denoting height.

Upon the completion of the initial curve, a second and third curves were developed for the basal diameter-height curve (Fig. 2) and the height-age curve (Fig. 3). The second curve consisting only of *C. lauuense* specimens, the third of *C. secundum* specimens. These curves were designed the same as the first basal diameter-height curve (Fig. 2) and age verses heigh (Fig. 3).

FIGURE 15. IMAGE OF LAUUENSE SAMPLE DEMONSTRATING GOOD ORIENTATION AND ONLY ONE VISIBLE LASER POINT.

FIGURE 16 (RIGHT). IMAGE OF SAME LAUUENSE SAMPLE DEMONSTRATING POOR ORIENTATION AND BOTH LASER POINTS VISIBLE.

CHAPTER III

RESULTS

The *Corallium sp.* ages ranged from 8.2 years to 47.5 years based on radial diameter measurement and using the radiocarbon derived radial growth rate of 110 µm/yr (Roark et al., 2006). This shows that there is a wide range of ages of *Corallium sp* on the different seamounts. There is a strong relationship between the height and age of the coral.

Upon actually putting the images into the photoQuad software, I ran into some difficulties. I started with roughly 100 images from 20 different dive videos. After I reviewed them to put them into the software, I ended up with only 30 usable images as 27 images were either too pixelated or too blurry to get accurate measurements from. The other 43 pictures were of corals that could not be measured because of the orientation that the image was taken at, that it wasn't a complete image, or there were too many other things (wildlife or other corals) in the image to really be able to give an accurate measurement. Figure 15 demonstrates the complication of only having one visible laser point. Figure 16 is an image of the same specimen, from a different angle where the orientation of the coral is unusable and is an example of one of the major issues encountered.

The images were measured with an assumed 10% margin of error that includes observer error, difference in the distance of the laser points depending on focal plane, and image quality. . First, the classification of the base differs with each image, based off of the orientation, the sample availability, and the difficulty of measuring a 3-D image in a 2-D medium. The last being the most difficult to work with. The orientation of the image can lead to small, but not insignificant difference in the distances measured. With a portion of the images, the only place that an image could be taken would lead to a portion of the sample being outside of the image frame.

After determining what constituted the base, the next issue was determining the top of end point of the sample to determine the height of the sample. With a majority of the samples, the top is not a solid end point, but rather a stem with many branches. This led to needing to extrapolate to the actual location of the topmost point of each sample. Multiple samples were large, and the branches all had different lengths and heights. Determining the average of those different branches led to additional uncertainties.

Second was the issue of the difference in laser point distance. That is to say, the difference in the refraction of the water partnered with the distance of the source of the light (the submarines) on the image background. At their ideal point, the distance of the laser points is ten inches apart. This value could potentially be slightly larger or smaller depending on the focal length of the lasers. To account for this, the distance for the lasers in the photoQuad calibrations was done at 25 cm to account for these potential differences. This also allowed for me to keep the value constant for every image.

The issue of image quality is very closely linked to the difficulty in measurements. While creating the recordings in the sub, it was difficult to stop the sub from moving and actually obtain a still image. Translate that to attempting to take a screenshot from stopping the video and it becomes very difficult to achieve a good quality image. Besides user issues, the images from the HD camera, when it was zoomed in, can be very poor quality as they are very pixelated.

TABLE 2 . ALL OF THE FIGURES USED. THE BASAL DIAMETER OF ALL SAMPLES IN COLUMN ONE. THE HEIGHT OF ALL SAMPLES IN COLUMN TWO. THE AGE CALCULATIONS IN COLUMN THREE.

Basal diameter (cm)	Height (cm)	Age (yr)	Species
1.1	15.5	16	Lauuense
1.5	12.8	13.3	Secundum
1.1	16.8	17.4	Lauuense
2.9	22.5	23.3	Lauuense
2.3	9.9	10.3	Secundum
1.9	21.7	22.5	Lauuense
1.9	32.2	33.4	Lauuense
1.2	28	29	Lauuense
2.7	27.2	28.2	Lauuense
1.5	20.6	21.3	Lauuense
2	33.1	34.3	Lauuense
1.3	25.8	26.7	Lauuense
1.5	21.5	22.3	Lauuense
0.9	34.5	35.7	Lauuense
1.1	46.1	47.8	Lauuense
1.2	8.2	8.5	Secundum
1.3	14.7	15.2	Lauuense
1.2	11.8	12	Secundum
2.5	17.7	18.3	Secundum
2.3	12.2	12.6	Secundum
1.1	7.9	8.2	Secundum
2.9	15.3	15.9	Secundum
2.1	11.7	12.1	Secundum
3.7	12.1	12.5	Secundum
1.6	14.2	14.7	Lauuense
1.9	21.3	22.1	Lauuense
1.4	13.6	14.1	Lauuense
3.8	40.9	42.4	Lauuense
2.4	32.7	33.9	Lauuense

TABLE 4. THE BASAL DIAMETER OF LAUUENSE SAMPLES IN COLUMN ONE. THE HEIGHT OF LAUUENSE SAMPLES IN COLUMN TWO. THE AGE CALCULATIONS IN COLUMN THREE. THE SPECIES NAME IN COLUMN FOUR.

Basal Diameter (cm)	Height (cm)	Age (yr)	Species
1.1	15.5	16	Lauuense
1.1	16.8	17.4	Lauuense
2.9	22.5	23.3	Lauuense
1.9	21.7	22.5	Lauuense
1.9	32.2	33.4	Lauuense
1.2	28	29	Lauuense
2.7	27.2	28.2	Lauuense
1.5	20.6	21.3	Lauuense
2	33.1	34.3	Lauuense
1.3	25.8	26.7	Lauuense
1.5	21.5	22.3	Lauuense
0.9	34.5	35.7	Lauuense
1.1	46.1	47.8	Lauuense
1.3	14.7	15.2	Lauuense
1.6	14.2	14.7	Lauuense
1.9	21.3	22.1	Lauuense
1.4	13.6	14.1	Lauuense
3.8	40.9	42.4	Lauuense
2.4	32.7	33.9	Lauuense

TABLE 3 (BELOW). THE BASAL DIAMETER OF SECUNDUM SAMPLES IN COLUMN ONE. THE HEIGHT OF SECUNDUM SAMPLES IN COLUMN TWO. THE AGE CALCULATIONS IN COLUMN THREE. THE SPECIES NAME IN COLUMN FOUR.

Basal Diameter (cm)	Height (cm)	Age (yr)	Species
1.5	12.8	13.3	Secundum
2.3	9.9	10.3	Secundum
1.2	8.2	8.5	Secundum
1.2	11.8	12	Secundum
2.5	17.7	18.3	Secundum
2.3	12.2	12.6	Secundum
1.1	7.8	8.2	Secundum
2.9	15.3	15.8	Secundum
2.1	11.7	12.1	Secundum
3.7	12.1	12.6	Secundum

The images that were usable created a very clear picture. One was that the two species had to be examined separately. The differences in the two species, C. lauuense and C. secundum, is great enough that when plotted together, no discernable relationship between basal diameter and height was evident.

The sample data is seen in tables 2, 3, and 4. The data points in tables 2 and 3 can all be seen in table 1. All of these data points were plotted into curves 1A and 1B.

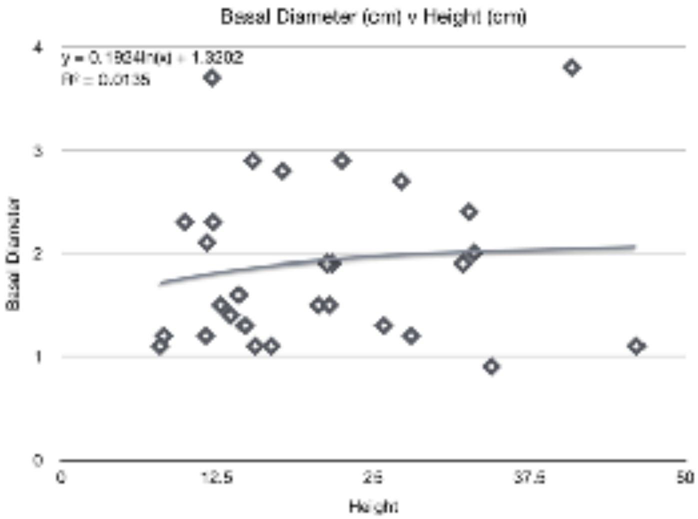
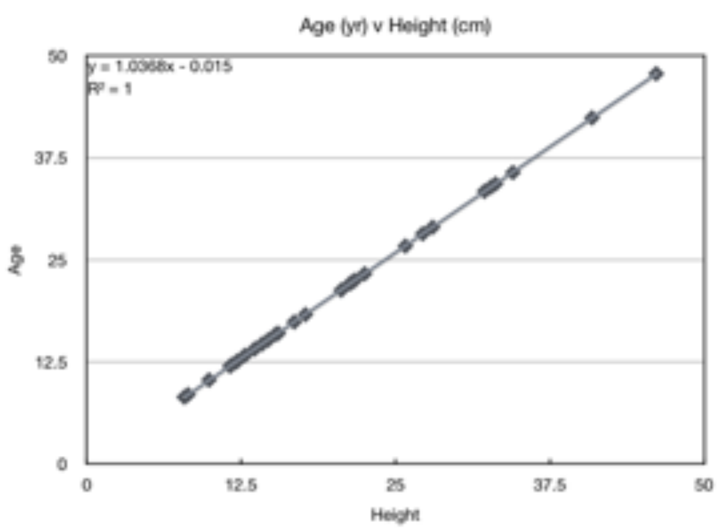


FIGURE 17. CURVE 1A. A SCATTERPLOT OF ALL SPECIES SAMPLE BASAL-DIAMETER VS HEIGHT DATA.

Results of the curves

The basal diameter verses colony height and the colony height verses age suggest that the height of a coral and age of a coral are closely related (Fig. 17 and 18) and that as a coral grows larger it is also growing older. Depending on the species, the size of the base varies with the age. C. secundum species tend to have a thicker base and not grow as tall. Their branches have a larger radius and do not extend out in a fan as the C. lauuense species does. This would skew the data because the growth structure of the two species are different in structural form. The presence of some very tall samples with exceptionally thick bases has played a role in skewing the

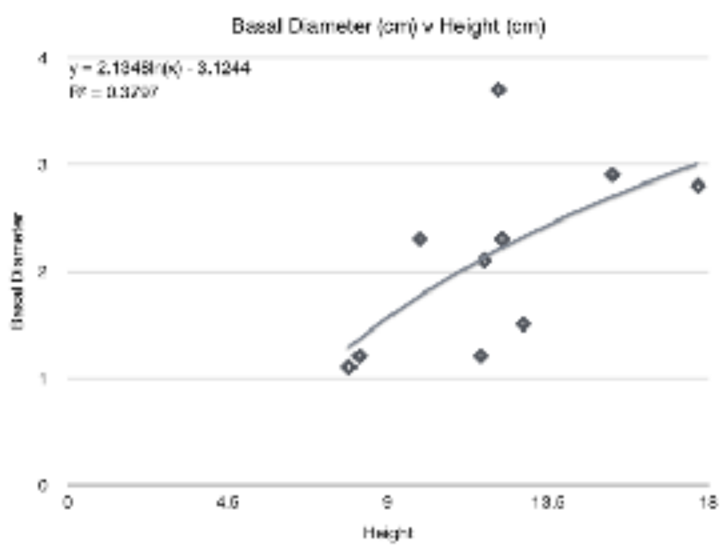
FIGURE 18. CURVE 1B. A SCATTERPLOT OF ALL SPECIES AGE VS HEIGHT DATA.



results. These outliers move the mean height and b-d thickness to larger heights and basal diameters, which also affected the regression line and R-squared value.

This came as quite a surprise because from on site observations, generally the bases of the corals looked larger as the coral specimens get larger. Some additional work that could be done to account for these variations would be to look at location of the corals. Were they found in specific environments? Was there an abundance of life around them? Did they occur where strong currents existed? Were they found on the base or top (the flat or gentled sloped areas) or on a steep side of the seamount? How big of a role does the difference in species make when accounting for the growth rates? Does depth or temperature play a role in growth patterns? Some ofthese can be answered through the dive logs. The population size, water temperature and depth, biodiversity, and sometimes the presence of an observable current were logged.

FIGURE 19. CURVE 3A. A SCATTERPLOT OF SECUNDUM BASAL-DIAMETER VS HEIGH DATA.



Species Curves

Basal Diameter vs Height curve

The basal diameter vs height curve of both species shows a positive relationship using a logarithmic correlation curve, but does not show any statistical significance (R^2 value of 0.0135) (fig. 17) With such a low R^2 value , there is no reason to believe that there is a relationship between the basal diameter and the height of a specimen. It is apparent that the basal diameter and colony height have no relation to each other. The logarithmic correlation has a stronger correlation than a linear correlation, however given its low R^2 values is not significant. Due to the results of the combined two species curve, I created two separate curves for C. lauuense and C.secundum.

When examining the species separately, things do look at bit different. The C.secundum b-d verses height correlation appear to be much more related when examined independently. Though they are more related, that does not mean that they are absolutely related. An R-squared value of 0.3797 (Fig. 19) is not indicative of closely correlated points. Rather it would suggest that there is a potential relationship between the two variables, but either the sample size must be larger to get more accurate results or there is another factor that is unaccounted for in this study. Both of these possibilities would require another study of similar data in order to determine their role in the results.

The C. lauuense b-d curve (Fig. 20) resembles the combined curve more closely than the C. secundum curve with an R-squared value of 0.116. The difference in growth pattern of the two species seems to be a more important controlling factor in the b-d to height relationship. From

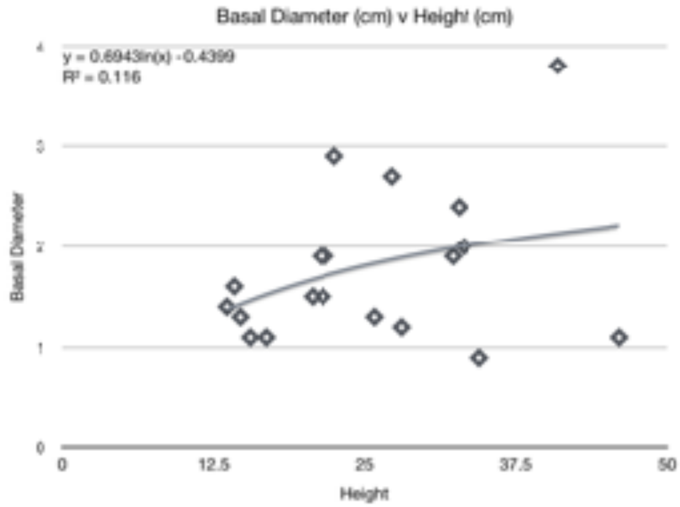


FIGURE 20. CURVE 2A. A SCATTERPLOT OF LAUUENSE BASAL-DIAMETER VS HEIGHT DATA.

in-situ observations, generally, the C. lauuense species has a smaller, thinner base which would equal to a smaller basal diameter.

It is significant to mention that the correlation increases by an order of magnitude from the combined curve, to the C. lauuense curve, to the C. secundum curve. This suggests that the closest b-d and height relationship is strongest in the Secundum logarithmic curve.

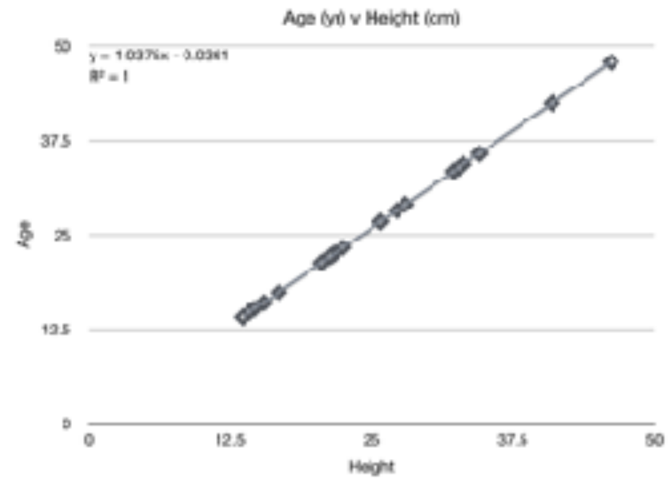
Age vs Height curve

The R squared value of a linear trend line for the age vs height curve for both species is 1 (Fig. 21). A R-squared value of 1 means that there is a statistical significance between the height of a specimen and its age. This is due to the fact that the age value was calculated with the height. Because of the absoluteness of an R-squared value of 1, it is difficult to recommend evaluating age based off of basal diameter at this time. Rather, the best bet would be to rely on height to extrapolate age, until the relationship between height and basal diameter is better understood. At this juncture we can reliably state that, with the use of the photoQuad software, a rough age estimate can be calculated. When broken down the C. lauuense curve also has a R-squared value of

1 (Fig. 21). Without a doubt, the height of the C. lauuense and the age of the C. lauuense are strongly correlated.

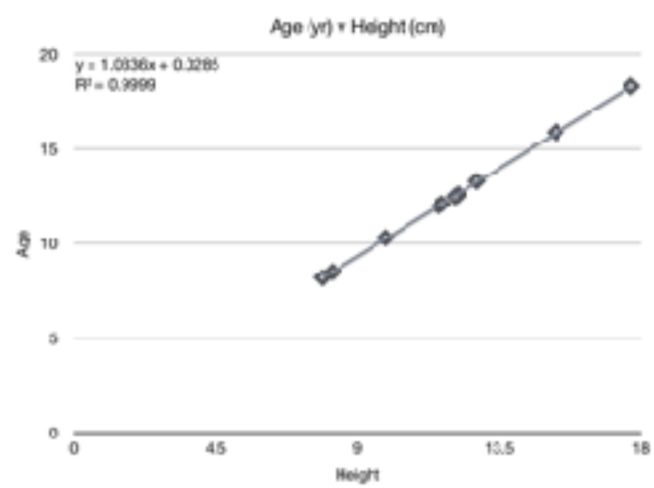
When broken down the Lauuense curve also has a R-squared value of 1 (figure 21).

FIGURE 21. CURVE 2B. A SCATTERPLOT OF LAUUENSE AGE VS HEIGHT DATA.



Without a doubt, the height of the Lauuense and the age of the Lauuense is strongly correlated.

FIGURE 22. CURVE 3B. A SCATTERPLOT OF SECUNDUM AGE VS HEIGHT DATA.



Despite the combined species regression lines R-squared value being 1 (Fig. 22) shows the C. secundums R-squared value is 0.9999. While that is close to 1, the deviation would suggest that at least one of the values doesn't fall exactly on the line. This could be a mathematical error from rounding the age values to one decimal point. It is also potentially contributed to a variance in the calculation of the R-squared value. Nevertheless, a value of 0.9999 would still shows there is a strong correlation which is to be expected given that how the age is calculated using a linear correlation of radial diameter and specimen age.

CHAPTER IV

DISCUSSION

The results suggest that the species must be studied individually in order to give the best possible results. Through the use of the photoQuad software, I was able to determine specimen ages based based on the height of specimen. The b-d and height ratio and curve was harder to evaluate, and suggest that there is no relationship between the two variables.

FIGURE 23 (BELOW). AN IMAGE OF A SECUNDUM SPECIES ON CALCIUM CARBONATE SUBSTRATE. IMAGE FROM PISCES IV DIVE 341 ON NOV. 2, 2017.

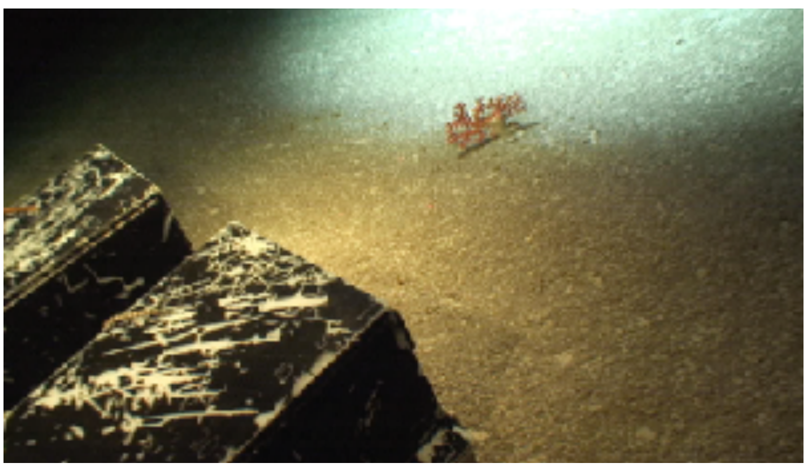


FIGURE 24 (BELOW). THE SECUNDUM SPECIMEN BEING TAKEN FOR SAMPLING AND TESTING. FROM PISCES IV DIVE 341 ON NOV. 2, 2017.

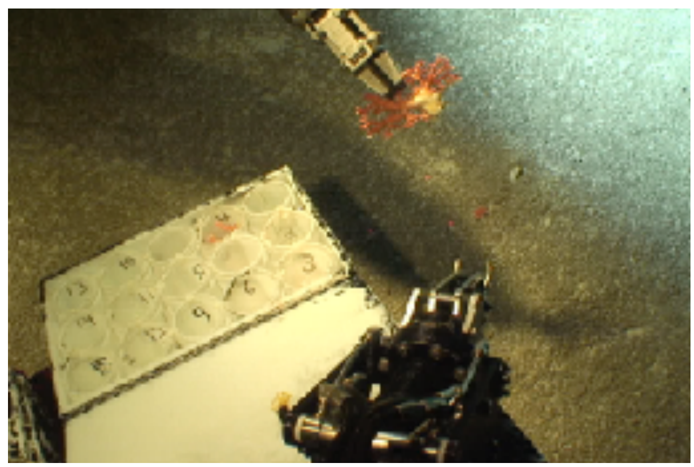
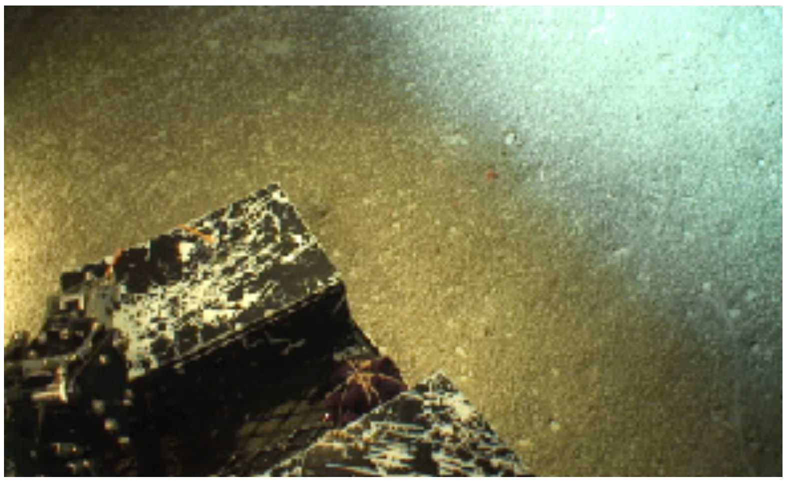


FIGURE 25 (RIGHT). AN IMAGE OF WHERE THE SECUNDUM USED TO GROW. TAKEN FROM PISCES IV DIVE 341 ON NOV. 2, 2017.

Importance

Having the ability to determine the coral specimens without removing them from the area is a critical to developing an size-age structure without destroying specimens. In the Pacific Ocean, there is less than one percent of the *Corallium sp.* present in the area than

was present in the 1980's. Japanese and Chinese fisheries have abandoned many locations in the Emperor Seamount Chain because of a decline in the quality of corals (Bruckner, 2009).
By not having to remove more Coralliades from the region as part of a fishery, fishing activites are no longer contributing to the destruction of the habitats.



Images 23, 24, & 25 document the effects of removing deep-sea corals from the ocean floor. Image 23 is the pristine C. secundum specimen. It has been untouched by anthropogenic forces. It sits on a hard calcium carbonate substrate. Image 24 was taken during the extraction process. The sample was plucked from its base on the carbonate substrate and was placed into a sampling container. This happened on majority of the dives, some samples were taken for genetic sampling (which had to be taken) and voucher samples (the sampling that can be partially eliminated by dating via image). Image 25 is what the substrate looked like post sample removal. For small samples like this one, the entire specimen was removed. With larger samples, only a portion of the specimen is removed, causing less damage. When possible, the goal is to eliminate all unnecessary removal of any coral species from the ocean floor.

Corallium sp. serve as keystone species in their environments. They are important for the biological development of commercial fish (Roark et al., 2006). These species similarly serve as integral parts of the overall biodiversity in the region. From the fish and other mega fauna living in the ecosystem, to the range of other corals that are routinely found in conjunction with the *Corallium sp.*. The strong correlation between the photoQuad measured heights and the calculated ages is the first step to eliminating the need for collecting a large number of voucher specimens to be removed from a seamount for dating purposes.

Offenders

The nature of the research itself is cutting edge. It is the next step in sustainable research and scientific advancement. The overarching goal and reason we want to date the specimens is to ascertain the recovery rate of *Corallium sp.* in the region. Knowing the recovery rates will provide a means of assessing the longer terms effects of fishing (or overfishing in some cases) in the region. Comparing the three different treatment types demonstrates the scale of human destruction in these areas and can serve as a benchmark for other regions.

Late 2017, President Trump proposed shrinking size of Papahannamokuakea in order to expand fishable seas (Pala, 2017) This act goes to show the blatant disregard for future generations and their well beings. What is blatantly obvious as a bad idea to those who have seen the Monument, doesn't have an economic value so it is disregarded. What is not taken into account in Trumps decision to shrink the Monument is that pristine land and water does in fact possess an economic value. The valuation of the natural environment is not easy, but it cannot be disregarded as unimportant. It comes down to willingness to pay. How much are people willing to pay to protect these lands (and waters)? The Hawaiian peoples, when given the chance, would do whatever it takes to save and protect their waters (Office of Hawaiian Affairs website.)

Over the long-term, the use of the photoQuad software to age *Corallium* sp. will serve as a benchmark for potential future research. The results from photoQuads use will also work to create paleoenvironmental frameworks to study and create reconstructions of the past and near present. Reconstructing environmental changes in these regions is important to ascertaining the recovery rates of the corals in these regions.

Jewelry:

The DSC jewelry industry is vital to the Hawaiian and East Asian trade industry. For decades a variety of coral species were harvested from both the deep ocean and the surface oceans. Corals are not particularly fast growing species. There are stipulation on how large a coral must be before it can be harvested. For example, there is a minimum vertical height requirement of 10 inches for *Corallium sp.* in Hawaiian waters. Sustainable yield catch limits also exist. (Roark et al., 2006.) There is a steep decline in the number and quality of *Corallium sp* . (Bruckner, A. 2009). By no longer removing as many coral samples for dating, more specimens will be present in the regions and allow for a longer recharge time. This time is invaluable to the recovery of the species.

Fishing:

Despite the fact that the already decimated seamounts that were once teeming with life are still being fished, fisherman will now be expanding into the only recharge zones left in the region. There will no longer be any sustainable fishing yields that can be taken from the northwestern Pacific Ocean. The *Corallium sp*. are indicators of the population size in a given location. When they are transformed into a desert region it is apparent there is trouble in the waters. Removing the fish from the area is extremely harmful to the delicate ecosystems themselves, but the way it is done is more troubling.

These waters are fished via trawling. A fishing vessel drops a giant net attached to weights and steel doors into the water. The net is then dragged along the bottom, effectively removing all life from the substrate. Again, by no longer contributing to the removal of more corals by using the photoQuad software to date corals, there will be a greater abundance of corals to combat their destruction by fishing and trawling.

Future Work

Due to the nature of the basal-diameter to height curve, more will have to be done to find the relationship between the two. The b-d was known to be difficult to measure, and the software was not effective in making such measurements. The data, when applied to the variety of seamounts, can be used to calculate the overall well-being of the *Corallium sp*. In doing this, documenting the affects of fishing on the region will be easier. The recovery rates of these species is also indicative of the health of the entire ecosystem. By calculating reliable height-age curves, we can state the relationship between the variables, limiting the need to take samples out of their habitats.

The goal is to be a part of the solution, not to contribute to the problem. With the extant of harm that is happening to these seamounts due to fishing, it is no longer beneficial to remove unnecessary corals in the name of science. Evaluating the recovery rates of the *Corallium sp*. creates a picture of the past to determine the direction of the future. The photoQuad software is an inexpensive and reliable solution making the discovery of recovery rates more easier. Its use will make possible to document anthropogenic changes in a variety of different ways. With this research in the deep Pacific, it allows the documentation of those human-influenced changes in the farthest reaches of the world.

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